A MERCURY RELAY WHICH OPERATES IN ANY PLANE

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INTRODUCTION

Mercury switching devices have been a standard for life and reliability in the electromechanical industry. Two basic shortcomings have been size and position sensitivity. By the use of mercury films, a unique switching device has been developed which offers the advantages of mercury contacts in a very small package. Operation is permitted in any mounting plane as well as in moderate environments of shock and vibration.

This paper describes the principles of design and the theory of operation of this device. Coil actuated relays and magnetically actuated switches are discussed. A new principle of latching memory is introduced. The inherent capabilities and limitations of mercury film switching are presented. These capabilities are compared to other switching devices in order to put this new product into proper perspective for potential users.

PRIMARY DESIGN GOALS

Mercury Wet

The benefits of mercury switching in the areas of contact capability, life and reliability, bounce free operation and low and stable contact resistance are well known. These capabilities led to the utilization of a mercury switching mechanism.

Latching

Most switch-relay systems are designed for the more common monostable or non latching operation. If a latching property is desired it is usually adapted after the monostable design criteria are met. The resulting latching mechanisms are compromises by design and intent and users have learned to live with their characteristics. The device discussed here must provide an inherent latching mechanism with the ability to provide monostable operation in final packaging.

Position Insensitivity

The two design goals mentioned above are not unique by any means. However, up until now the chief limitation of mercury switching was position sensitivity. The final primary design goal was therefore position insensitivity.

Secondary Goals

The primary goals listed above were supplemented by the requirement that the device should be compatible with the small size and sensitivity of todays circuitry.

BASIC CONSTRUCTION

An extensive research and development effort over a period of several years has produced a switching element which meets both primary and secondary design goals.

Parts

Figure 1 shows the basic switch assembly and identifies these elements:

1. Pole Pieces and Contacts are approximately .020" diameter glass sealing magnetic alloy which serve as the

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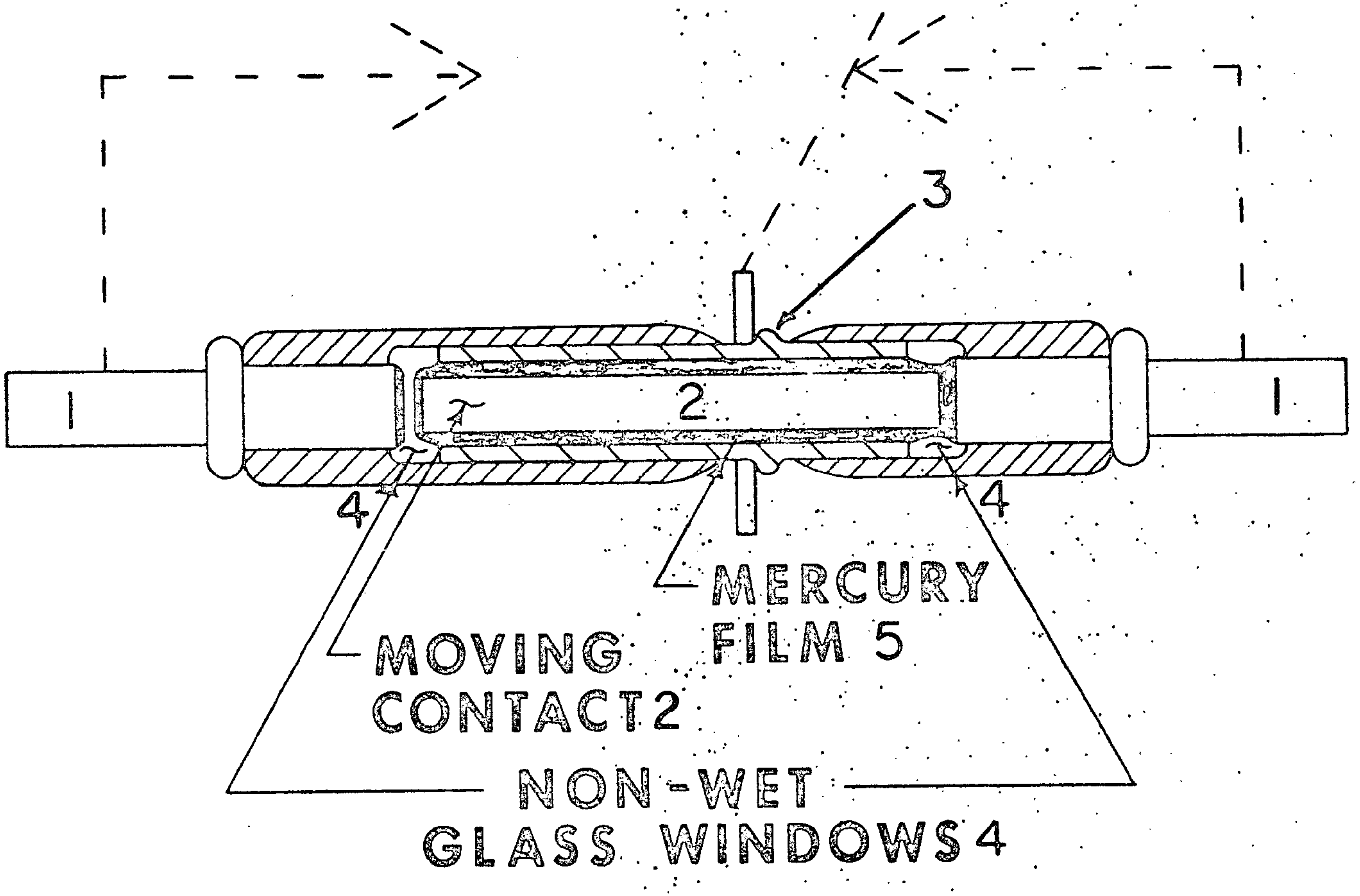


Fig. 1 -- BASIC CONSTRUCTION (1. Pole Pieces and Contacts; 2. Armature; 3. Center Barrel; 4. Glass Seals; 5. Mercury).

stationary electrical contacts and connections.

2. Armature is a magnetic material which is free to glide back and forth between the end contacts. It is in electrical contact with the center barrel at all times through a mercury film and acts as the moving armature in the switch.

3. Center Barrel is a glass sealable tube which provides external electrical connection to the moving arm or armature.

4. Glass Seals provide glass to metal hermetic seal for the switch assembly.

Materials

As can be seen above, the pole pieces and center barrel must be glass sealable. Portions of the center barrel must be wettable with mercury as must appropriated portions of armature 2 and pole piece contacts to provide mercury switching surfaces. Finally, pole pieces and armature must be magnetically susceptible to respond to magnetic actuation.

OPERATION PRINCIPLES

Mercury

In conventional mercury wet systems, mercury depletion at the contacts is a significant design problem due to droplet formation, thermal pumping, vaporizing, splashing, tilting, dewetting, etc. The conventional solution is to provide a sufficiently large mercury reservoir and communicate it to the contacts by means of a system of capillaries.

This device takes the opposite approach. Sufficient contact mercury is provided by limiting the amount which can be carried by the space and surfaces other than those of the "contacts". This is accomplished by making the non wet surfaces and volumes small compared to wetted ones. (See Figure 2)

The behavior of the mercury system during operation is a result of basic laws of surface tension which cause the mercury volumes to constantly tend to form the shape with the least free surface energy. At rest, the mercury can be seen to concentrate in the shaded areas of Figure 2(a). A small amount of mercury is on the open left hand contacts. The majority of the mercury is between the armature and center barrel. The armature design is such that appropriate portions of its surface are mercury wet and thus share mercury with the inner surface of the center barrel. Other portions are non wettable in order to provide a buoyant surface on which the armature will float. This mercury body continues along the surface of the armature outside the center barrel to the right hand end probe where mercury film contact is maintained.

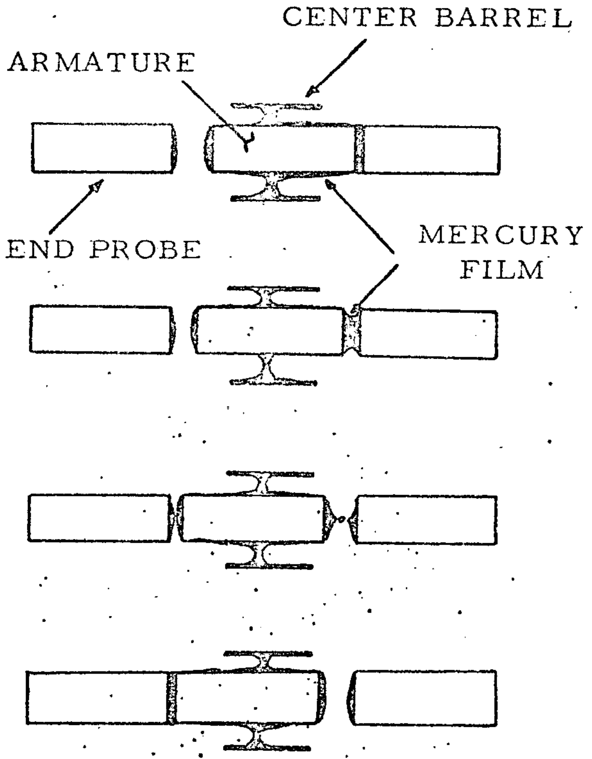


Fig. 2 -- MERCURY SYSTEM OPERATION
(Armature motion is from right to left).

Figure 2b shows the start of the slug motion as a filament of mercury is begun to be drawn out. This action involves the overcoming of the surface tension forces which inherently hold the armature in contact with the end probe. A filament stretches until in 2(c) the surface tnesion forces are insufficient to maintain it. At this point the filament snaps with some mercury remaining on the end probe, some on the armature, and some in the form of a tiny droplet which will either fall directly into the end probe or center barrel mercury or remain on the non wet glass "window" before being drawn back into one of the adjacent wet surfaces of mercury. The armature continues to move into 2(d) until film contact is made on the opposite end and the surface tension forces again pull the armature into a latched position against the end probe. Note that the armature can communicate a mercury film from one end to the other. It is not, strictly speaking, a contact. The switching is performed by a mercury film.

By adjusting internal geometries, the present design may be adapted to form C mode (break-before-make) or form D mode (make-before-break). The magnitude of the surface tension is sufficient to hold the tiny three milligram armature and its mercury in place with a force of about 5g's. Because the masses and volumes are so small, the effects of gravity are dwarfed with respect to the surface tension forces. This provides the position insensitivity and inherent latching performance.

Magnet

While the mercury system gives the device the desired switching performance, the magnetic circuit will provide the key to operating the device.

Figure 3 shows the magnetic circuit elements. Item 3 is a magnetically conductive washer which is welded to the center barrel during assembly to facilitate electrical contact to the center-barrel. To operate the switch opposite magnetic poles must be established in the open gap and/or like magnetic poles must be established in the closed gap. By establishing opposite poles in the closed gap the magnetic force may be used to increase the latching force. Also, under dynamic conditions the slug will follow a moving attractive force, (as a magnet), or behave like a solenoid with a coil.

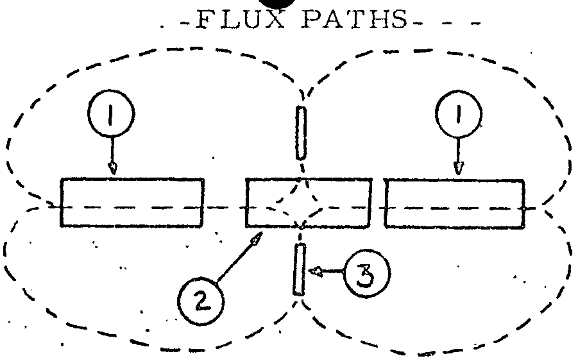


Fig. 3 -- MAGNETIC CIRCUIT ELEMENTS
(1. Pole Pieces and Contacts;
2. Armature; 3. Washer).

OPERATION

Switch

Having described basic mercury and magnetic circuits the next step is to consider the requirements of the device as a magnetically actuated switch. With many possibilities open for switch use we will try only to highlight basic principles.

Any magnet actuator will be most effective if the majority of its flux is directed through the open gap of the switch which we desire to close. Figure 4 illustrates several ways of magnet actuation. In each case it must be remembered that the inherent surface tension latching characteristic will hold the switch operated until it is switched back to the other side. This memory is unique in that it is not polarity sensitive. The same or opposite polarity may be used to set and reset the switch. Monostable operation and stronger latching forces may be obtained by the use of bias magnets in the switch package.

Relay

Packaging is analogous to switch operation. Typical configurations are shown in Figure 5. Again bias magnets in packaging may be used to obtain specific operating parameters. Shields and flux path directors may be used to improve the efficiency of operation.

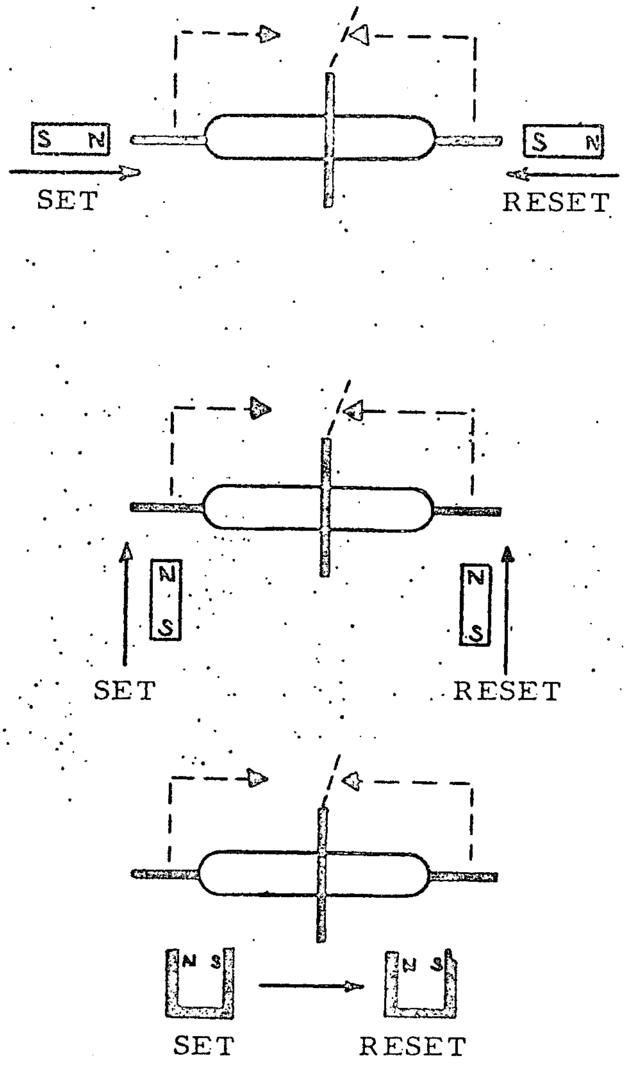


Fig. 4 -- PERMANENT MAGNET ACTUATION

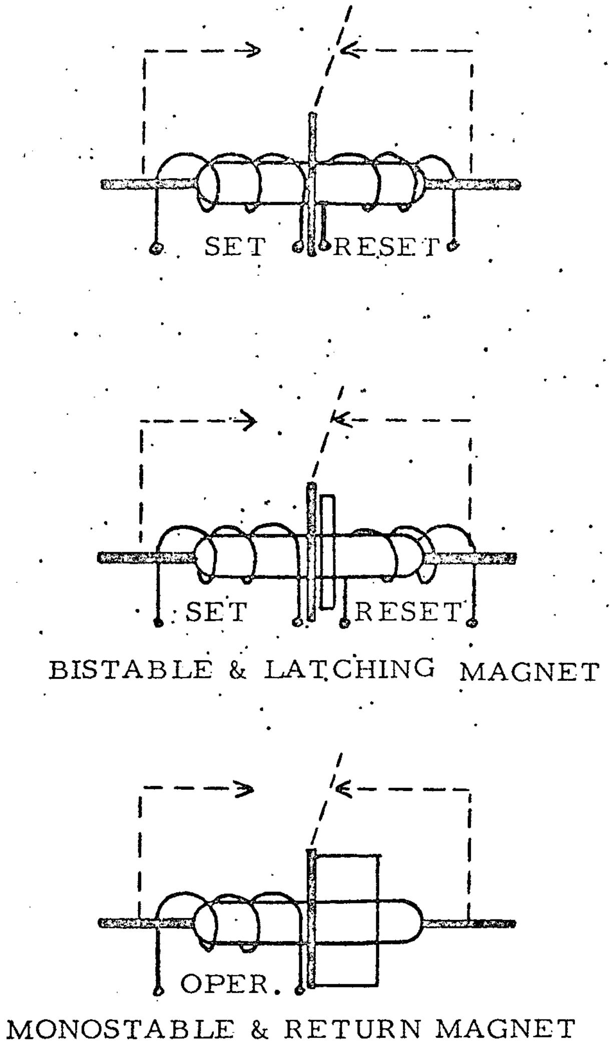


Fig. 5 -- COIL ACTUATION

APPLICATIONS

With basic principles of construction and operation outlined, the benefits and limitations of this switching device will be summarized.

Physical

Position Insensitivity - From the outset position insensitivity has been a realized goal. The mercury surface tension forces (with or without magnetic assistance) hold the contacts switched regardless of position.

Size and Weight - With a switch volume of .01 cubic inch and weight of .1 grams, adequate compatability with todays circuitry is achieved.

Electrical

Contacts - As expected with mercury switching, contact performance is excellent. Unlike hard contact devices, there is no contact interface once the device has been operated. Therefore, the contacts closely approximate a solid conductor. Closed resistance is near .035 ohms made up primarily of lead material and therefore varies less than one milliohm over life of a billion operations. Life (within ratings) is independent of load. The armature design which allows the mercury to circulate to each wetted surface in the relay allowing a new contact to be formed with every operation. There is no wear or erosion since the mercury film does the switching. Each new contact actuation uses new mercury and even if contact mercury is vaporized by high current on break, fresh new mercury is fed to the armature tip to make fresh contact on the next closure. This provides further advantage of being able to switch between "dry circuit" and "power" loads with equal performance in each case. The contact load capability is charted in Figure 6. Without contact protection, current should be limited to 50 ma when voltage is over 20 VDC. Other values as shown will all give performance in excess of one billion (1 x 10^9) operations. (Up to the internal thermal power limitation). While resistance to overload is good, any severe overloading of contact ratings can cause failure. Also some candom missing has been noted (about one operation in ten million) due to contact flooding which clears on the very next operation. Finally, signal distortion is extremely small. Rise time of 10^{-12} seconds, lack of bounce, low thermal (DC) and magnetostrictive (AC) noise and low RFI all combine to protect the signal being carried.

Package - When combined with the package appropriate to the application the above characteristics may be preserved and improved, to the users advantage.

Environment - With any mercury contact the lower temperature limitation is the freezing point of mercury (-38°C). At higher temperatures amalgam formation may be precipitated resulting in failure. The present device is therefore limited to +70°C ambient. It is felt that this may be improved in the future. Shock and vibration sensitivity have been lightly touched on earlier. The basic switch capability of latching may be augmented to levels limited only by the magnetic force available to unlatch or operate the switch. Since the capsule is hermetically sealed under controlled conditions, the contacts are well protected from surrounding environments of humidity, salt, dirt, evaporation or loss of mercury.

Examples - The principles and characteristics discussed above are now being used by designers in a variety of applications. Listed below are some specific examples and benefits by which the subject switch has shown significant advantages over alternative switching devices.

Digitally Programmed Analog Computer- offers equipment non volatile memory and long life in minute size.

Process Control Recorder- provides limit switch of small size with memory and no mechanical linkage.

Liquid Level Indicator- advantages include hermetically sealed contact enclosure, small size, and no mechanical linkage.

Airborn Multiplexing System- gives small size, weight and long life.

Phase Array Radar-, used as 50 ohm strip line relay.

Automatic Test Circuit- used for 50 ohm high speed pulse transmission.

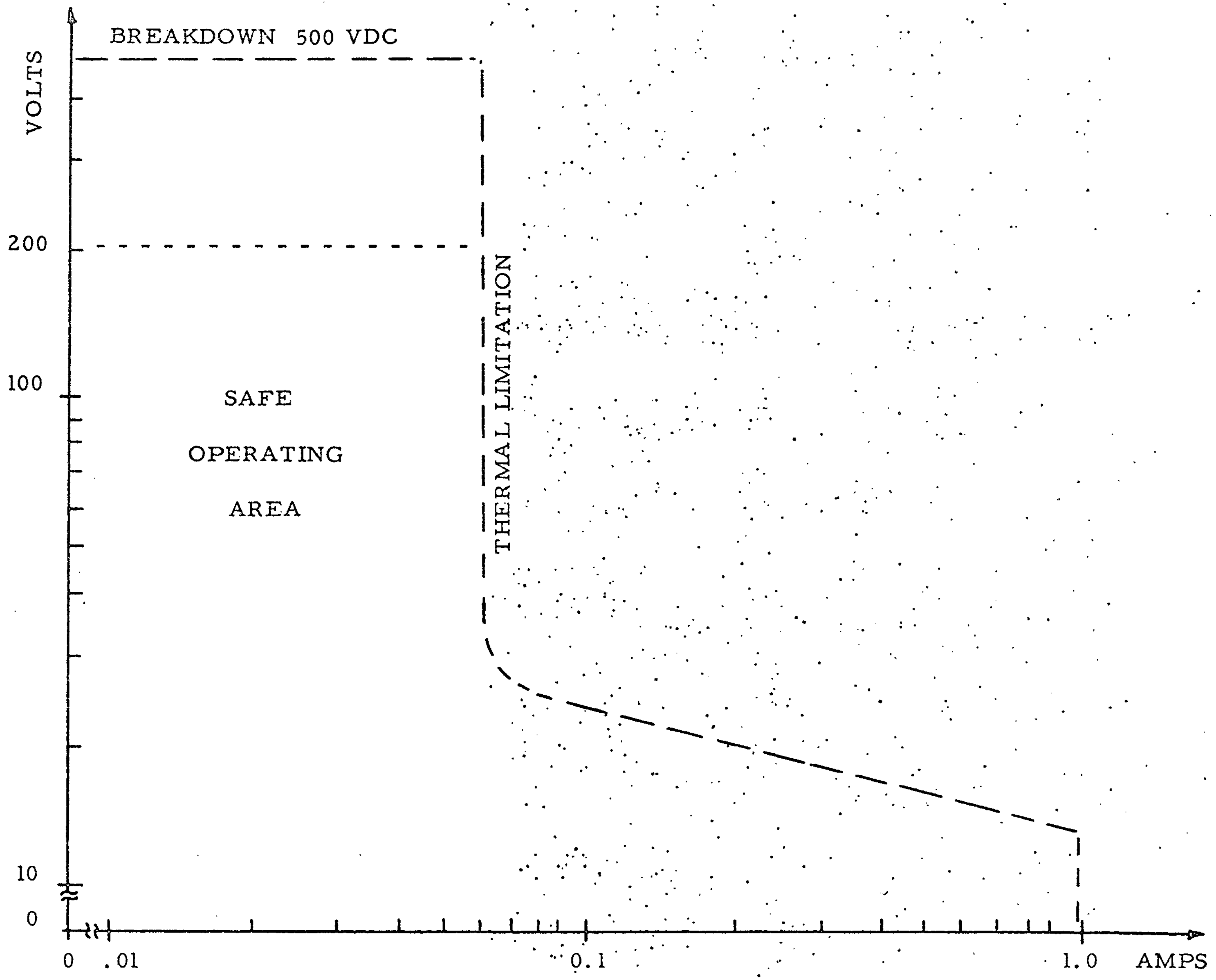


Fig. 6 -- CONTACT CAPABILITY (without suppression).

TABLE I

A Microminiature Mercury Film Switch/Relay compared to Selected Switching Devices.

	Parameter	Subject Switch	Crystal Can Relay	Dry Reed Relay	Hg Wetted Relay	Transistor Circuitry
1.	Size (cubic inch)	0.01 to .06	.4 to 3	.02 to 1.6	.2 to 4	*
2.	Operate Time (millisec) (Excl. Bounce)	1 to 2.5	3 to 8	.5 to 5	.8 to 6	.01
3.	Contact Bounce Time (millisec)	0	.2 to 5	.2 to 3	0	0
4.	Sensitive to Position	No	No	No	Yes	No
5.	Typical Life @ Rated Load (Operations)	10^9	10^6	10^7	10^9	*
6.	Contact Resistance (ohms)					
	Initial	.027	.035	.050	.025	1
	Final	.027	1	2	.025	1
	Variation	± .005	+1	+2	±.002	**
	@ Dry Circuit	.1	50	50	.1	
7.	Open Contact Resistance (ohms)	10^{10}	10^{10}	10^{10} to 10^{14}	10^{10}	10^5 to 10^7
8.	Memory After Power Removal	Yes	Yes	Yes	Yes	No
9.	Rise and Fall Time	Excellent	Good	Good	Excellent	Fair
10.	Transient and Overload Tolerance	Good	Good	Poor	Good	Poor
11.	Thermal Offset Voltage	Excellent	**	Fair	Good	Poor
12.	AC Noise	Excellent	Good	Poor	Fair	Excellent
13.	RF Switching (50 ohm)	Excellent	Fair	Fair	Fair	Fair
14.	RFI	Excellent	Poor	Poor	Poor	Excellent
15.	Environmental Capability	Fair	Excellent	Good	Poor	Excellent

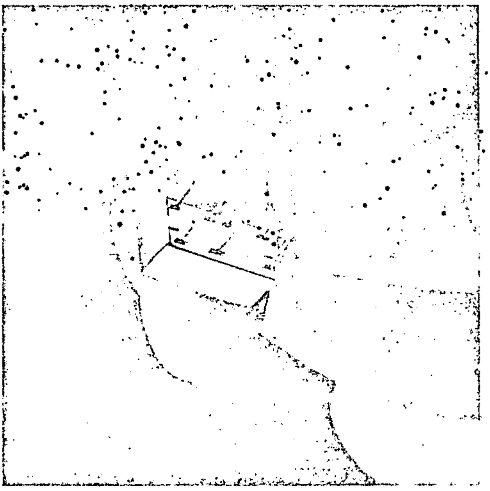
* Significantly better than subject switch but difficult to quantify.

** Unknown or not applicable.

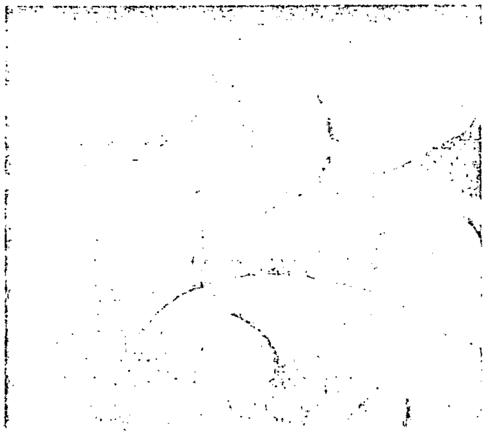
LOGCELL

*Long life
and no-bounce operation
in any mounting position*

Logcell Mercury Film Relays and Switches represent an entirely new approach to switching. Unlike conventional mercury switching devices, Logcell relays and switches require no mercury reservoir. Instead, they contain an almost microscopic element that responds to the presence of a magnetic field by gliding on a thin film of mercury to merge two mercury-film contacts. The advantages of this approach are:



LOGCELL MERCURY FILM RELAY



LOGCELL MERCURY FILM SWITCH

OPERATION IN ANY POSITION – operation is completely independent of mounting position

MINIATURE SIZE – relays occupy 0.06 cu. in.; switches occupy 0.0004 cu. in

HIGH RELIABILITY – test units have been cycled more than five-billion times with no detectable change in contact resistance

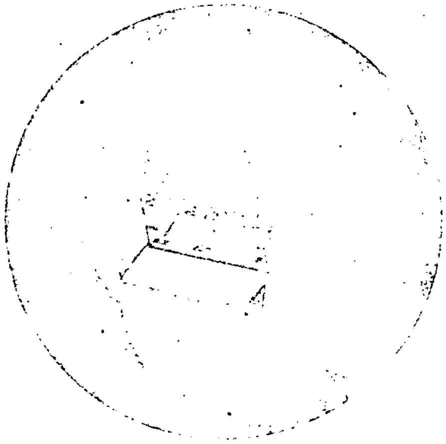
NO CONTACT BOUNCE – each actuation provides a bounce-free Form C transition from an open circuit to a perfect closure

DEPENDABLE DRY CIRCUIT SWITCHING – contact is achieved by the merging of two mercury films; contact resistance is less than 50 milliohms

NO NOISE – AC noise is below instrumentation levels; thermal noise is less than 1 microvolt

INHERENT CONTACT MEMORY – contact remains in its last position until reactuated – no latching current or external magnetic field required – monostable models also available

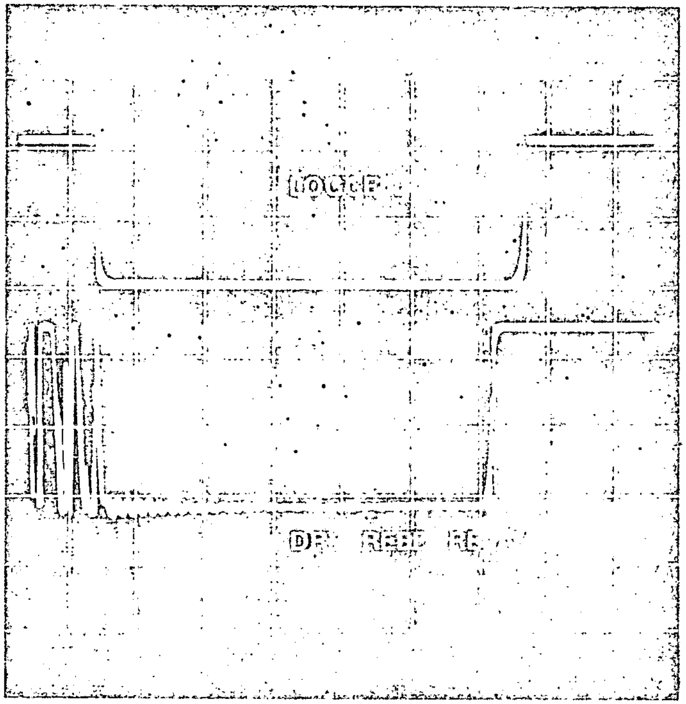
SHOCK AND VIBRATION RESISTANCE – suitable for many airborne, marine and other mobile applications



LOGCELL MERCURY FILM RELAY

Logcell Mercury Film Relays are Form C devices which combine the versatility of dry reed relays with the reliability and bounce-free operation of mercury-wetted contacts. They afford the equipment designer complete freedom of location because they can operate in any position, even under moderate levels of shock and vibration. The contacts of Logcell Relays are self healing. AC noise is below measureable levels, and thermal noise is well under 1 microvolt. Both bi-stable (latching) and mono-stable (non-latching) models are available.

MERCURY FILM RELAYS

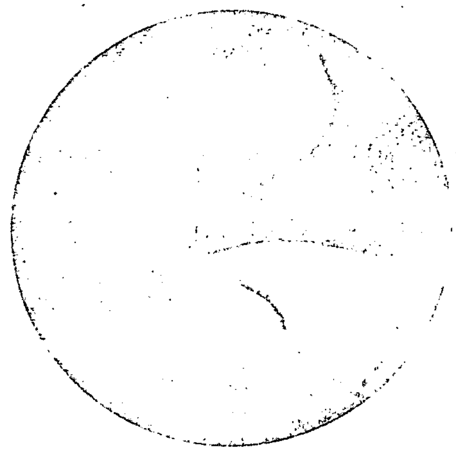


Absence of contact bounce and contact noise is shown by oscillogram of Logcell Relay. Unit under test has been operated over four-billion cycles. Operation of a new dry reed relay is shown for comparison purposes.

How Logcell Relays and Switches Work

MERCURY FILM SWITCHES

Logcell Mercury Film Switches are the smallest magnetically operated switches available. They incorporate all the advantages of Logcell Relays except that they are actuated by the motion of an external permanent magnet rather than by an electromagnetic coil. Of primary importance to the equipment designer is the inherent memory of Logcell switches. After the energizing magnet has closed one of the switch contacts, that contact will remain closed regardless of further extension of the magnet. Only the reverse travel of the magnet will cause the contact to open and the switch reset to its original position.

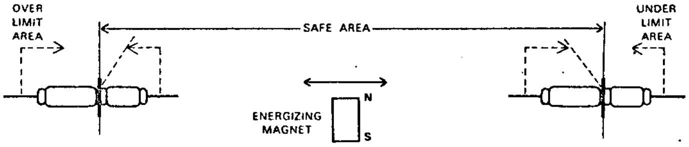


LOGCELL MERCURY FILM SWITCH

Typical Logcell Switch Applications

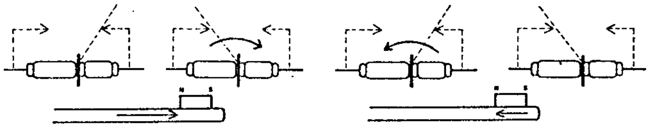
LIMIT SWITCHING

Inherent memory of Logcell Switch eliminates need for holding circuitry. Passage of magnet from "safe" area across either one of the limit switches will operate that switch. Switch will remain actuated until magnet moves back across it into "safe" area.



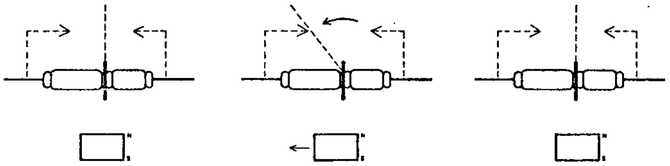
CONTROL ROD POSITIONING

Precise control of rod position in a mechanical system can be obtained by locating Logcell Switches at selected points and attaching a permanent magnet to the rod.



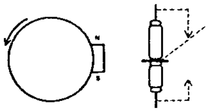
CENTER-OFF SERVO CONTROL

By centering a special magnet on the main axis of a Logcell Switch, both switch contacts will be held open. Should magnet move in either direction, the switch will close in that direction. Closure can be used to actuate a drive system to return the magnet to its center (null) position.



ROTATION COUNTER OR PULSER

Actuation of Logcell switch by a magnet attached to a rotating shaft will produce a pure, no-bounce square wave whose length is a function of the speed of rotation.



ROTATION CONTROL

Properly biased Logcell Switch will detect change in direction of shaft rotation. Switch's inherent memory will latch to indicate direction of rotation.

PUSHBUTTONS OR TOGGLE SWITCHES

Logcell Switches are ideally suited for push-button or toggle switching of dry circuits. They maintain extremely low contact resistances even at loads of less than 10 microvolts.

The Logcell Switch is the heart of the Logcell Relay. Within a hermetically sealed capsule is a single moving contact, an almost microscopic three-milligram element that glides on a thin film of mercury between two stationary wetted contacts. This capsule, as small as a pencil point (0.04" D x 0.25" long), is the Logcell Switch. Its Form C contact mechanism is passive as well as self healing. It can be actuated by the field of a user supplied permanent magnet

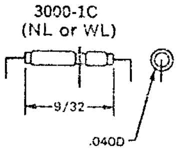
Logcell Relays consist of a Logcell Switch plus two coils and a permanent magnet to control the position of the switch element. Actuation of the relay changes an essentially infinite resistance to a contact resistance of less than 50 milliohms in less than 2.5 milliseconds. Both the switch and the relay can be operated in any position, even under shock and vibration, due to the low mass of the moving element and the high surface tension of the mercury film.

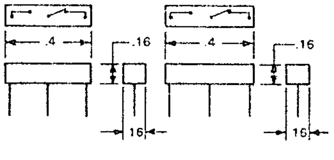
(Numerals in parentheses refer to notes at bottom of table.)

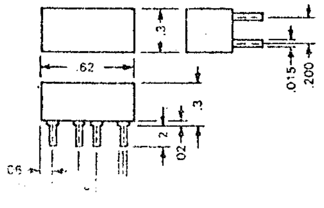
	Series 8120-1A Bistable Relay	Series 8120-1C Bistable Relay	Series 8210-1A Monostable Relay	Series 8210-1C Monostable Relay	Series 3000-1C (NL or WL) (1) Basic Bistable Switch	Series 3100-1C Shock Resistant Bistable Switch In Protective Package	Series 3200-1C Shock Resistant Monostable Switch In Protective Package
Life at Rated Load	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Max. Contact Switching VI	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Contact Breakdown VDC (6)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Contact to Contact Capacitance	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Initial Contact Resistance	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Contact Resistance Variation Over Life	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Open Contact Resistance	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Contact Rise Time — Typical	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Operate Time at Rated Coil Volts (2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Release Time	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Bounce Time	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Thermal Noise (5)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AC Contact Noise	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Contact Configuration	[illegible]	[illegible]	[illegible]	[illegible]	SPDT	[illegible]	SPDT
Maximum Cycling Rate	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Coil Resistance (ohms) ±10%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3 VDC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NA	[illegible]
6 VDC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NA	[illegible]
12 VDC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NA	[illegible]
24 VDC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	NA	[illegible]
Minimum Coil Drive Pulse Length (Milliseconds) (2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Coil to Contact Capacitance	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Minimum Operate Ambient Temperature	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Maximum Operate Ambient Temperature	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Shock Resistance (No Permanent Damage)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Shock Resistance Axial Plane (No False Operations)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Shock Resistance Other Planes (No False Operations)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Vibration Resistance Axial Plane (No False Operations)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Vibration Resistance Other Planes (No False Operations) (All Vibration 100-2000 Hz)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Relative Permanent Magnet Sensitivity (3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

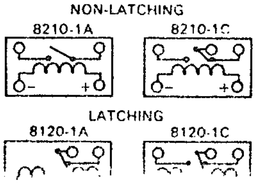
Specifications subject to change without notice.

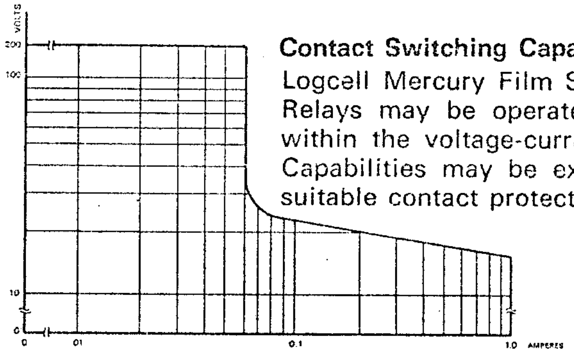
1. Basic Switch may be furnished without leads (NL) or with 1½" flexible leads (WL).
2. Consult factory for faster models.
3. Distance at which switch will operate when energized with standard magnets *A3792-1, **A3792-2
4. NA = Not applicable.
5. Bi-stable Model.
6. Form A and C.











Contact Switching Capability

Logcell Mercury Film Switches and Relays may be operated anywhere within the voltage-current diagram. Capabilities may be extended with suitable contact protection.

Ordering Information

8	1	2	0	—	1	C	—	12
Logcell Series	1. Latching 2. Nonlatching	No. of Coils	Special		No. of Poles	Contact Form		Coil Volts or Type

FIFTH DIMENSION INC.
Box 483, Princeton, New Jersey 08540
Telephone (609) 924-5990

PRINTED IN U.S.A.

FIFTH DIMENSION INC.
P. O. BOX 483 • PRINCETON, NEW JERSEY
WALNUT 4-5990

LOGCELL NET PRICE LIST

Quantity	Series 3000-1C-NL	Series 3000-1C-WL	Series 3100-1C	Series 3200-1C	Series 8120-1A	Series 8120-1C or 1D	Series 8210-1A	Series 8210-1C or 1D	Series D-C or D-D
1 - 9	$11.00	$11.00	$12.10	$12.10	$16.10	$17.80	$15.60	$15.90	$21.80
10 - 24	10.60	10.60	11.65	11.65	14.50	16.00	14.05	14.25	19.70
25 - 49	10.15	10.15	11.20	11.20	13.73	15.19	13.27	13.47	18.60
50 - 99	9.71	9.71	10.70	10.70	12.92	14.25	12.50	12.70	17.50
100 - 249	9.40	9.40	10.30	10.30	12.10	13.40	11.75	11.90	16.40
250 - 499	8.95	8.95	10.00	10.00	11.30	12.50	10.95	11.10	15.30
500 - 999	8.40	8.40	9.42	9.42	10.50	11.60	10.17	10.32	14.20
[illegible]000-4999	7.95	7.95	8.90	8.90	10.00	11.00	9.70	9.80	13.50
5000 up	7.50	7.50	8.40	8.40	9.70	10.70	9.35	9.45	13.15

Terms - Net 30 days
FOB - Princeton, N.J.
Effective Date - 12/15/68